

## MOVEMENT OF CHLORIDE INTO A WELL-DRAINED SOIL

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## Abstract

Chemical leaching from soil surface will cause groundwater pollution. Researches showed spatial correlation of the leaching chemicals. Based on the fact, a filed research was conducted at Maury silt loam soil (fine, mesic, mixed, Typic Paleudalf) to evaluate spatial variations of anion movement, in tis case was Cl<sup>-</sup>, into and below rooting zone. Source of chloride, SrCl<sub>2</sub>.6H<sub>2</sub>O, was evenly distributed on soil surface within a 18 x 18 m<sup>2</sup> plot in University of Kentucky Experimental Station, Lexington, Kentucky USA. Soil was sampled for 4 times (after receiving 166, 310, 586, 1085 mm rainfall), in every 10 cm depth for 54 points within the plot. The result showed that Cl<sup>-</sup> movement did not show spatial model from soil surface into 100 cm profile in every sampling date. Therefore, based on analysis of variance, Cl<sup>-</sup> concentration was significantly different from one depth to another within one sampling time. Cl<sup>-</sup> concentration found on the depth of 100 cm was 75, 58, 27, and 15% for sampling time I, II, III, and IV, consecutively.

**Key Words:** groundwater pollution, anion leaching, agricultural chemicals, spatial structure

## INTRODUCTION

Anion exclusion can be an important factor contributing to loss of anions from soils (Thomas and Swoboda, 1970; Smith, 1972). Bond *et al.* (1984) stated that the exclusion of anions, from the diffuse double layer at the surface of chemically reactive clay soils significantly affects the shape of the salt concentration profile and, in particular, the position of the salt front.

The adsorption capacity of a soil is important in withholding cations, while Cl<sup>-</sup> and NO<sub>3</sub><sup>-</sup> are transported with water down the soil profile, because they are readily soluble. Van de Pol *et al.* (1977) determined the rate of movement of Cl<sup>-</sup> and 3H in a field soil. They found that the average value of solute concentration and water flux at any soil depth depends upon the pore water velocity distribution which is also affected by spatial variability of the soil. Chloride movement was more uniform and had a larger diffusivity (D) value,  $39 \times 10^{-5} \text{ cm}^2 \text{ sec}^{-1}$  in a soil core and in repacked soils than that in natural field soil; this might be caused by different pore connectivity patterns (Elrick and French, 1966). White *et al.* (1984)

reported the apparent velocity of Cl<sup>-</sup> movement was always greater than that of 3 HOH which suggested that the mobile volume involved in convective and diffusive transport of Cl<sup>-</sup> was less than that for 3 HOH.

Some factors contributing to Cl<sup>-</sup> leaching in soil profiles are pore size, macropores, cation exchange capacity (CEC), water content, tillage practices, solute concentration, texture, structure, and organic matter content. A relatively large continuous pore is another important flow property (Germann *et al.*, 1984). A large continuous pore was an especially important pathway for chloride movement through saturated swelling clay soils (Kissel *et al.*, 1973). Steenhuis and Muck (1988) reported that nutrients in macropores were lost much more rapidly than in macropores.

Water that functions to exclude Cl<sup>-</sup> was mobile water. The percentage of water that excluded Cl<sup>-</sup> decreased as the salt concentration (N CaCl<sub>2</sub>) increased. This is due to the salts entering between clay layers rather than a collapse or partial collapse of the layers (Thomas and Swoboda, 1970).

Kissel *et al.* (1973) found that Cl<sup>-</sup>

movement within the plow layer of a field soil was more uniform because of frequent mixing of soil by tillage. Cultivation might change the presence of natural cracks and channels that cause the gradual leaching (Wild, 1972).

Steenhuis and Muck (1988) studied the movement of  $\text{Cl}^-$  and  $\text{NO}_3^-$  on wet, shallow sloping soils and found that up to 60% of that applied could be lost in surface runoff.

Soils having relatively coarse texture near the surface (Ghuman et al, 1986) and soils with strong structure (Tyler and Thomas, 1981) caused rapid downward displacement of  $\text{Cl}^-$ . While soil organic matter helps in temporarily retaining  $\text{Cl}^-$  in the soil surface. Smith (1972) reported that  $\text{Cl}^-$  moved through the soils 1.04 to 1.67 times faster than it would have if it had been associated uniformly with all the soil water. Increases in  $\text{Cl}^-$  movement were also correlated with CEC and surface area of the soils. Soils having high negative charge, anions will move much faster than they would where no interaction with the clay occurs (Thomas and Swoboda, 1970).

Quisenberry and Phillips (1976) reported that water content and chloride concentration increased at the 60 cm depth of a field soil after one hour application (4.14 cm) of water. In another study nearly 60% of the 4.14 cm application of  $\text{Cl}^-$  tagged water had percolated past the 90 cm depth within 1.5 hours. Chloride loss and its location, for most the part, was in the lower depths in the profile which proved that it was the applied water that was moving through the profile and not displacing much of the initial water.

Chloride ( $\text{Cl}^-$ ) is an anion like  $\text{NO}_3^-$ . Since they have the same charge (minus 1) it

is estimated that they have the same pattern of movement in soil profile. Due to the fact that  $\text{NO}_3^-$  can be lost both through leaching and through volatilization, therefore,  $\text{Cl}^-$  was applied to predict the fate of  $\text{NO}_3^-$  in soil profile after receiving several amounts of rainfall.

## MATERIALS AND METHODS

This research was conducted at University of Kentucky Agricultural Experiment Station, at Lexington, USA from 1989 until 1990. Chloride in form of  $\text{SrCl}_2 \cdot 6\text{H}_2\text{O}$  solution (with  $\text{Cl}^-$  concentration  $2725 \text{ ug cm}^{-2}$ ) was sprayed on surface of Maury silt loam soil (fine, mixed, mesic, Typic Paleudalf). This soil has dark brown, very friable silt loam, and moderate, granular structure surface layer (which occurs to a depth of 35 cm), and reddish brown, friable silty clay loam that grades into silty clay in the lower part into 95 cm depth) as well as has high natural fertility, medium organic matter content, moderate plant moisture supplying capacity and moderate permeability. The site has not been cultivated for approximately 40-60 years. Grass and small weed covering the soil surface were killed using glyphosate a week prior to chemical application.

Samples were taken 4 times in approximately a one-year period corresponding to different amount of cumulative precipitation (as presented in Table 1) by using a soil core sizing 3.176 cm in diameter and 1 m in length. The geometry of each sample number and the position of soil sampling on each sample date were shown in Figure 1.

Table 1. Sampling dates and precipitation on the experimental site during the field study.

Sampling Date	Precipitation (mm)*	
	Between dates	Total to Each Date
Sept 27-1989 (I)	166**	166
Nov 20-1989 (II)	144	310
Jan 03-1990 (III)	276	586
July 25-1990 (IV)	499	1085

\*) Precipitation distribution is attached \*\*\*) Amount of precipitation received from application (August-1989) of  $\text{SrCl}_2 \cdot 6\text{H}_2\text{O}$  to the first sampling date.

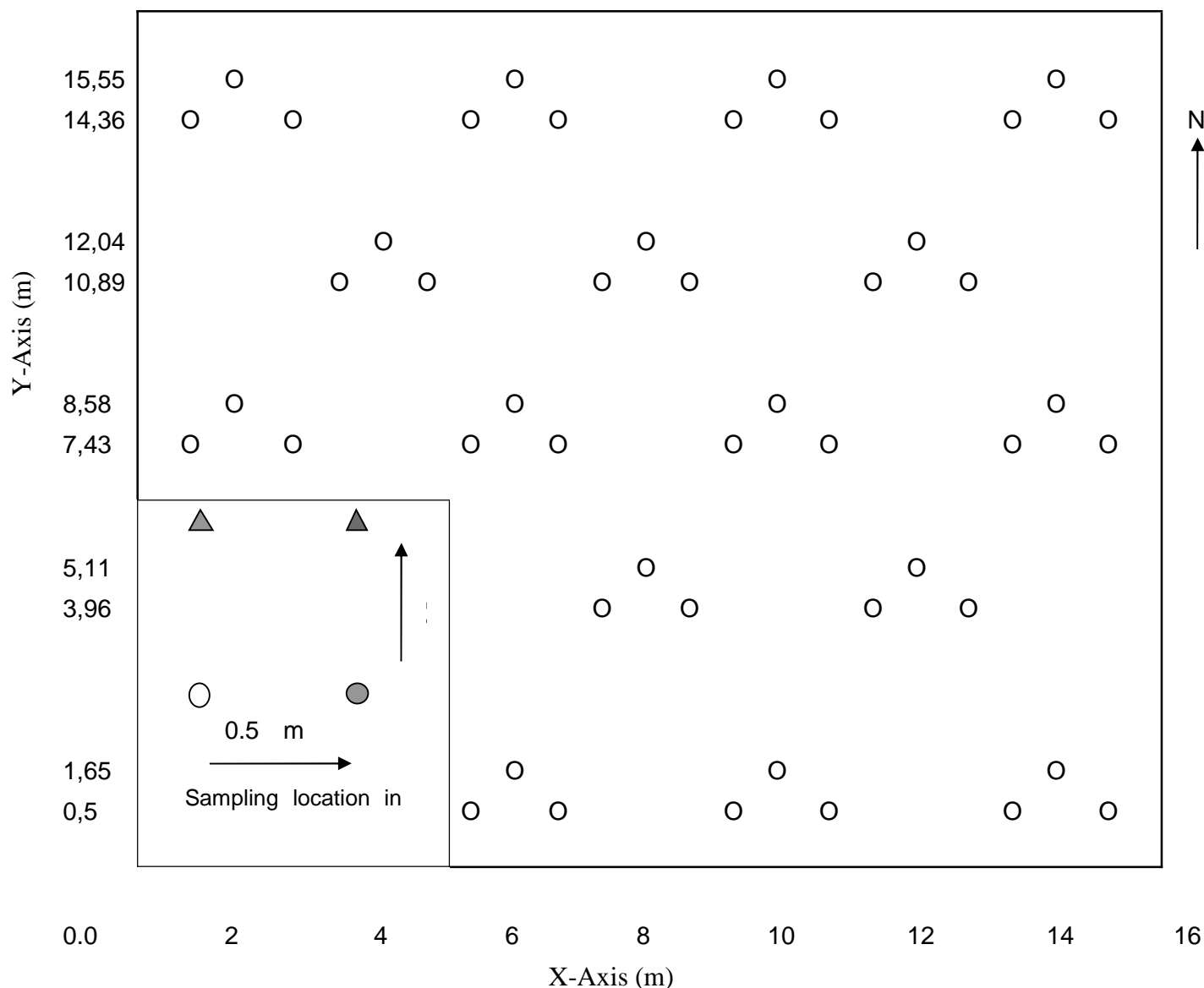


Figure 1. X-Y coordinates of each 54 sample sites in the field study and sampling location in each sampling date

Soil samples were separated in each 10 cm depth and saved in plastic bag. Ten (10) g of each sample was analysed for  $\text{Cl}^-$  concentration by extracting it using 1 M  $\text{NH}_4\text{OAc}$  adjusted to pH 7.0, then it was measured by using Orion Ionalyzer. Concentration of  $\text{Cl}^-$  obtained was analyzed using a geostatistical software program<sup>1)</sup> to evaluate the spatial variability. Isotropic semivariogram and correlogram analyses

were run the sum of the ten depths of each sampling date and each of the ten depths within each sampling date. If the data were not spatially correlated, analyses of variance using (ANOVA) using Fisher Statistics would be run. Mean separation value of  $\text{Cl}^-$  concentration among depths within sample date was evaluated using the Least Significant difference (LSD).

## RESULTS AND DISCUSSION

Isotropic semivariograms analyses of  $\text{Cl}^-$  concentration distribution in the profile of Maury silt loam soil are presented in Figures 2,3,4 and 5 for sampling date I, II, III, and IV, respectively. Chloride did not show any spatial structure in any of the four semivariograms, as well as for each of the ten depths at each of the four sample dates (Figures not presented). As found by Shaddiq *et al.* (1985) that some soils showed little spatial dependence and some had no spatial arrangement among the samples. Slight spatial structure was reported by Smettem (1987) for sorptivity measured at small suction (-100 mm water potential), whereas in situ steady-state ponded

infiltration rate had no spatial structure.

Average of  $\text{Cl}^-$  data are presented in Table 2, and the distribution is plotted in Figure 2. Chloride moved deeper into soil profile in each succeeding sampling date due to more and more water infiltrating and moving the chloride downward in the soil profile. Based on the analyses of variance,  $\text{Cl}^-$  movement was significantly different both among sample dates and among depth within sample date. Chloride movement is greatly influenced by water movement in macropores due to a much greater quantity of water moving down through the macropores than in the soil matrix. This fact causes nonuniform movement of  $\text{Cl}^-$  in soil.

Table 2. Mean value of  $\text{Cl}^-$  concentration ( $\mu\text{g cm}^{-3}$  soil) of each depth at four sampling dates after receiving 166, 310, 586, and 1095 mm precipitation, respectively.

Soil Depth	Sample Date			
	I	II	III	IV
	9-27-1989	11-20-1989	3-1-1990	7-25-1990
..... cm .....	..... $\mu\text{g cm}^{-3}$ .....			
0-10	41 a	12 cd	6 d	3 bc
10-20	33 b	10 de	1 f	1 d
20-30	39 ab	14 cd	1 f	1 d
30-40	39 ab	27 b	2 ef	0 d
40-50	24 c	34 a	8 c	1 cd
50-60	13 d	28 b	16 a	4 b
60-70	7 de	17 c	16 a	8 a
70-80	5 e	9 de	14 ab	8 a
80-90	3 e	6 ef	12 b	8 a
90-100	2 e	3 f	4 de	8 a
% Recovery	76	59	29	15

\*) Treatment mean followed by unlike letters are significantly different at ( $P < 0.05$ )

depth. The highest concentration of  $\text{Cl}^-$  was in the 0-10 cm depth (41  $\mu\text{g Cl cm}^{-3}$ ), however, it was significantly different from the 20 to 30 cm and the 30 to 40 cm depths. The concentration of  $\text{Cl}^-$  in the 80-90 and 90-100 cm depths was low, almost background. However, only 76% of that applied was

recovered in the 0 to 100 cm depth at sample date I which meant that 24% of  $\text{Cl}^-$  added had moved below the 100 cm soil depth. Higher  $\text{Cl}^-$  concentration in the 0-10 cm depth was due to soil organic matter which functions temporarily to retain anions in soil surface (Ghuman and Lal, 1986).

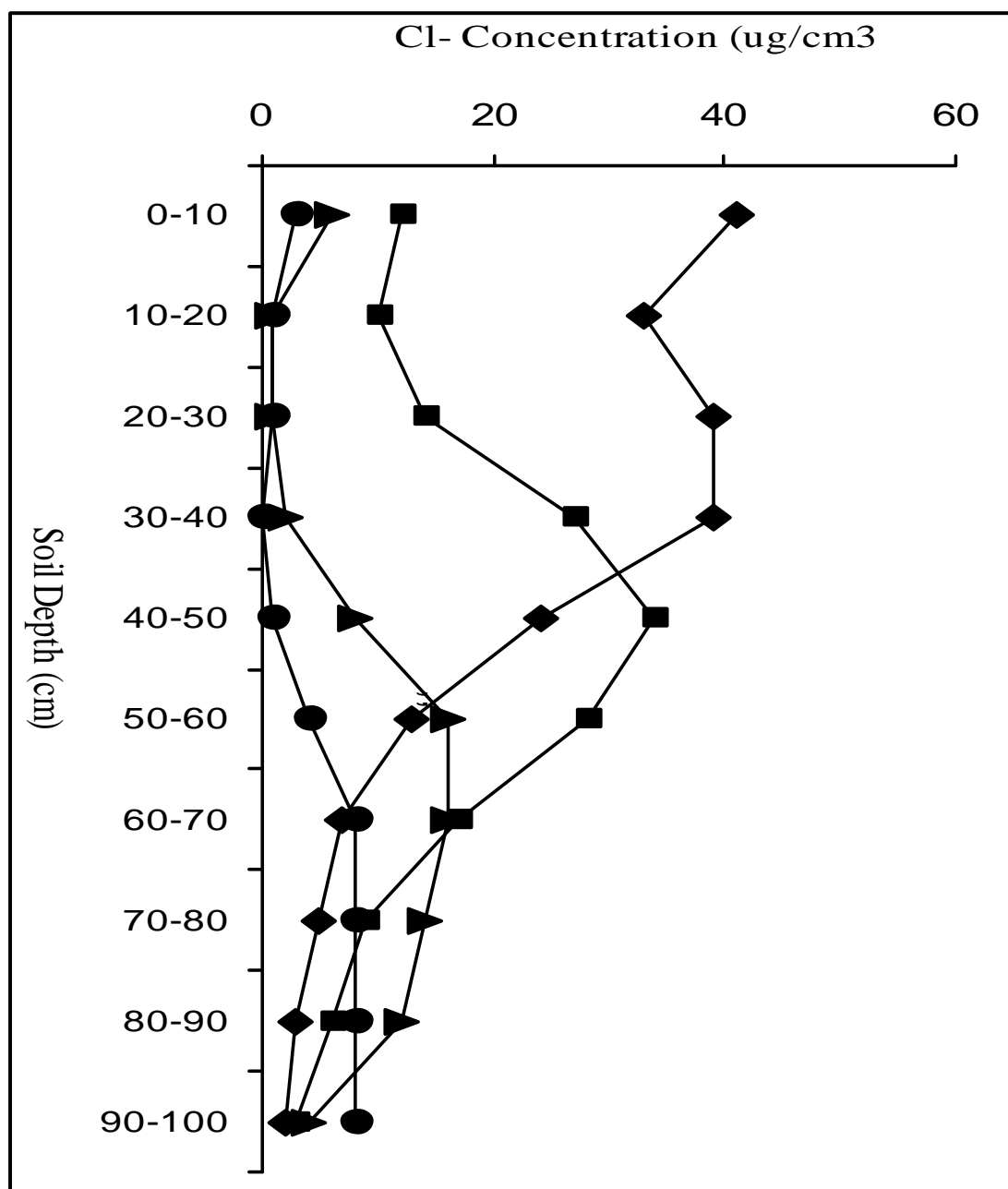


Figure 2. Average of chloride movement deeper into soil profile in each succeeding sampling date due to more and more water infiltrating in the soil profile.

At sampling date II, the highest  $\text{Cl}^-$  concentration had moved to 50-60 cm depth. Most of the  $\text{Cl}^-$  (about 66% of amount  $\text{Cl}^-$  recovered at this sample date) was concentrated at the 20-70 cm depth. The value of  $\text{Cl}^-$  concentration in the soil surface down into the 40 cm depth decreased at sample date II compared to sample date I; on the other hand, it increased in the depths below. The % recovery of  $\text{Cl}^-$  concentration at sample date II was 17% less than that at the first one.

The concentration of  $\text{Cl}^-$  recovered at sample date III, was 30% less than sample four depths, 60-100 cm. These values were 8  $\mu\text{g cm}^{-3}$  but they had 76% of the  $\text{Cl}^-$  recovered at this sample date. The  $\text{Cl}^-$  concentration in every depth decreased compared to sample date III, except for the 90-100 cm depth. The percent recovery was 15% of  $\text{Cl}^-$  applied or 14% less than at sample date III after receiving an additional 499 mm precipitation.

Starr et al. (1986) found similar results at three sampling dates following application of a 5cm- 0.015 M  $\text{CaCl}_2$  pulse. In the Ikom soil, a well-structured clayey soil in Nigeria,  $\text{Cl}^-$  moved beyond the 90 cm depth after infiltration of 8 cm of water (Ghuman and Lal, 1986). Tyler and Thomas (1977) found that higher  $\text{Cl}^-$  was leached from no-till than conventional till of Maury silt loam soil. McMahon and Thomas (1974) found that the movement of  $\text{Cl}^-$  was deepest in undisturbed samples for Maury and Eden soils, due to their large pores. Wild (1972) found that the  $\text{NO}_3^-$  concentration decreased in the surface horizon and increased deeper in the soil profile. He found the ratio of distance of  $\text{NO}_3^-$  movement to the amount of rainfall received varied between 0.3 to 0.7.

## CONCLUSIONS

Based on the above result, it can be concluded that  $\text{Cl}^-$  moved deeper into the soil profile as the amount of precipitation increased. The percent recovery of  $\text{Cl}^-$  in 1-m depth of soil profile was 76, 59, 29, and 15% of the amount applied at each sampling date, respectively. It means that 14, 41, 71,

and 85% of  $\text{Cl}^-$  had moved below the 100 cm depth after receiving 166, 310, 586, and 1085 mm precipitation, respectively. The value of  $\text{Cl}^-$  leaching per mm precipitation were 4.0, 3.2, 2.9, and 0.8  $\mu\text{g cm}^{-3}$  soil for sample date I, II, III, and IV, respectively. Since  $\text{Cl}^-$  movement did not show spatial correlation, it means that macropores in Maury silt loam soil are also randomly distributed date II or 47% less than sample date I. The distribution of  $\text{Cl}^-$  with depth indicated that a higher concentration had moved into the lower depths compared that at sample date II. Most of  $\text{Cl}^-$  (73% of  $\text{Cl}^-$  recovered at this date) was concentrated in the 50-90 cm depth. The highest  $\text{Cl}^-$  concentration was found at the 50-60, 60-70, and 70-80 cm depths.

Eighty five percent of the  $\text{Cl}^-$  had leached below the 100 cm depth at the last sample date, after receiving 1085 mm precipitation. Significantly higher concentrations of  $\text{Cl}^-$  were found in the last

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